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(71) Applicant: OPTIKOS CORPORATION [US/US]; 286 Cardinal Medeiros Avenue, Cambridge. MA 02141 (US).

(72) Inventors: FANTONE, Stephen, D.; 340 Summer Street, Lynnfield, MA 01940 (US). ANTHONY, Brian, W.; 9 Beacon Street, Somerville, MA 02144 (US). SEVIGNY, Kevin, M.; 318 Merrimac Street, Newburyport, MA 01950 (US). WILK, Stephen, R.; 38 Fairchild Avenue, Saugus, MA 01966 (US).

(74) Agent: CAUFIELD, Francis, J.; 6 Apollo Circle, Lexington, MA 02173 (US).

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(54) Title: OPTICAL HEIGHT OF FILL DETECTION SYSTEM AND ASSOCIATED METHODS

(57) Abstract

The height–of–fill of a container comprising a body having an optically detectable feature, and contents filling the body up to a fill level, at least a measuring portion of the container extending from the optically detectable feature to the fill level being capable of transmitting electromagnetic radiation, is determined by illuminating at least the measuring portion of the container with electromagnetic radiation; forming an image of part of this measuring portion of the container; and analyzing the image by data processing means to identify: (a) a first region having a first intensity that varies in accordance with the properties of the optically detectable feature; and (b) a second region having a second intensity that varies in accordance with the optical properties of the contents below the fill level, and determining the distance between a point within the first region and the upper edge of the second region, thereby determining the height–of–fill.

OPTICAL HEIGHT OF FILL DETECTION SYSTEM AND ASSOCIATED METHODS

This invention generally relates to the field of measurement of the fill level of the contents of containers at least part of which is transparent, and more

5   particular to optical means by which the height of fill can be measured in such containers, for example glass or plastic bottles, whether of clear or colored glass or other material. The term "transparent" is used herein to mean capable of transmitting electromagnetic radiation at an adopted working wavelength band, not necessarily within just the visible region. For example, certain embodiments of the

10   invention use infra-red radiation, and can thus be used with glasses which are transparent in the infra-red though not in the visible.

Although the invention may be used for other purposes, for example measuring the height-of-fill (HOF) of pulverulent (e.g., powder) materials in glass ampoules, it is primarily intended to address the problem of measuring the HOF of

15   the fluid contents of transparent beverage containers, such as soda or beer bottles, to determine if they meet specifications for their volumetric content, which directly correlates to HOF for a known bottle geometry. While a bottle could possibly be stationary it is typically moving at appreciable speed while conveyed along a production line, so it is measured while moving, but at sampling rates that are

20   sufficiently fast so that the bottle appears "stopped" to the measuring optical system. Preferred embodiments of the invention have been tailored to meet the needs of bottled beers in clear, green and brown glass containers. As will be seen, the system preferably utilizes a line scan CCD imager to provide high-speed image capture.

Height of Fill is traditionally measured using an x-ray beam that is

25   set to 3 mm below the calibrated liquid level. When the beam signal changes, the fill is within limits, and produces a yes/no only answer to a Host control system, usually in the form of a computer of other suitable microprocessor based system.

Optical systems for measuring HOF are also known. For example, U.S. Patent No. 3,232,429 (Norwich) describes a fill level detector for use in

30   checking the HOF of bottles of foamable liquid passing along a filling line. The presence of a bottle at a measuring station is detected by a mechanical switch, and

two beams from light sources are passed through the upper end of the bottle on to

two photodetectors. Depending upon the output from the photodetectors, the bottle

is classified as acceptably filled, underfilled, or empty, and the latter two categories

of bottle are removed from the filling line by a mechanical rejection device. Since

5   this apparatus uses only two spaced photodetectors, only one of which detects the

presence of liquid contents lying beneath the foam in the bottle, it gives only a

yes/no answer as to whether the bottle is sufficiently filled and cannot measure the

actual HOF. Furthermore, since the HOF detection is made from fixed apparatus

lying alongside the filling line, the process cannot compensate for vertical variations

10   in the position of the bottle such as tend to occur when bottles are being transported

by a flexible conveyor.

U.S. Patent No. 5,414,778 (Schwartz et al.) describes an apparatus for

measuring HOF of a carbonated or similar fluid which is in a "dynamic state"

immediately after filling of a bottle. The somewhat elaborate process described in

15   this patent requires line-by-line analysis of a two dimensional image of a part of the

bottle, above and below the fill line produced by a video camera; this analysis serves

to identify not only the HOF but also the number and size of bubbles within the

liquid. To carry out such an image analysis on bottles on a commercial filling line,

which may be filling 1200 bottles per minute, requires a high powered computer,

20   and an expensive apparatus. Furthermore, the process described in this patent does

not attempt to allow for the presence of foam above the liquid, despite the fact that

such foam is inevitably present when many liquids, for example beer, are filled on

high speed filling lines.

The present invention provides a process and apparatus for

25   determining the HOF of a container; this process does not require the elaborate

analysis and computing power required by the Schwartz et al. process, but can

measure the HOF and allow for the presence of foam above the liquid. Preferred

embodiments of the present invention can compensate for variations in the vertical

height of the container, such as those which occur when the container is being

30   transported by a flexible conveyor.

Accordingly, this invention provides a first process for determining the height-of-fill of a container comprising a body having an optically detectable feature, and contents filling the body up to a fill level, at least a measuring portion of the container extending from the optically detectable feature to the fill level being

5   capable of transmitting electromagnetic radiation. This process comprises: illuminating at least the measuring portion of the container with electromagnetic radiation; forming an image of part of the measuring portion of the container; and analyzing the image by data processing means to identify:

(a)   a first region having a first intensity that varies in

10   accordance with the optically detectable feature; and

(b)   a second region having a second intensity associated with the contents below the fill level and which varies in accordance with the optical properties of the contents,

and determining the distance between a point within the first region and the upper

15   edge of the second region, thereby determining the height-of-fill.

This invention also provides a first apparatus for carrying out this first process and thus for determining the height-of-fill of a container comprising a body having an optically detectable feature, and contents filling the body up to a fill level, at least a measuring portion of the container extending from the optically

20   detectable feature to the fill level being capable of transmitting electromagnetic radiation. This apparatus comprises: image-forming means arranged to form an image of part of the measuring portion of the container; and data processing means for analyzing this image, the data processing means being programmed to identify in the image:

25   (a)   a first region having a first intensity that varies in accordance with the optically detectable feature; and

(b)   a second region having a second intensity, associated with the contents below the fill level, and which varies in accordance with the optical properties of the contents

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and to determine the distance between a point within the first region and the upper edge of the second region, thereby determining the height-of-fill of the container.

This first process and apparatus may hereinafter for convenience be called the "optical feature" process and apparatus of the present invention.

5   This invention also provides a second process for determining the height-of-fill of a container comprising a body, foamable liquid contents filling the body up to a fill level, and foam resting upon the liquid contents and extending from the fill level up to a foam level, at least an upper portion of the container extending from below the fill level to the foam level being capable of transmitting

10   electromagnetic radiation. This process comprises: illuminating at least the upper portion of the container with electromagnetic radiation; forming an image of part of the upper portion of the container; and analyzing the image by data processing means to identify:

(a)   a first region having a first intensity the varies in

15   accordance with the optical properties of the foam; and

(b)   a second region having a second intensity that varies
      in accordance with the optical properties of the liquid contents,
and determining the position of the boundary between the first and second regions, thereby determining the height-of-fill.

20   Finally, this invention provides a second apparatus for carrying out this second process and thus for determining the height-of-fill of a container comprising a body, foamable liquid contents filling the body up to a fill level, and foam resting upon the liquid contents and extending from the fill level up to a foam level, at least an upper portion of the container extending from below the fill level to

25   the foam level being capable of transmitting electromagnetic radiation. This apparatus comprises: image-forming means arranged to form an image of the upper portion of the container; and data processing means for analyzing this image, the data processing means being programmed to identify in the image:

(a)   a first region having a first intensity that varies in

30   accordance with the optical properties of the foam; and

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(b)   a second region having a second intensity that varies

in accordance with the optical properties of the liquid contents,

and to determine the position of the boundary between the first and second regions,

thereby determining the height-of-fill.

5   This second process and apparatus may hereinafter for convenience

be called the "boundary determining" process and apparatus of the present invention.

It will be apparent to those skilled in the art of container measurement that a single

physical apparatus may carry out both processes of the invention.

Figure 1 of the accompanying drawings shows a diagrammatic

10   perspective view of the apparatus of the present invention in use to measure height

of fill in bottles passing along a filling line;

Figure 2 shows an enlarged diagrammatic perspective view of the

light source assembly, bridge assembly, bottle detect assembly and optical assembly

of the apparatus shown in Figure 1;

15   Figure 3 is a flow diagram of the software used in the apparatus

shown in Figure 1;

Figure 4 is a diagrammatic vertical section through the axis of one of

the bottles shown in Figure 1;

Figure 5 shows the manner in which the apparatus shown in Figure 1

20   forms an image of the upper part of the bottle shown in Figure 4;

Figure 6 shows the manner in which the bottle shown in Figure 4 is

backlit in the apparatus shown in Figure 1, and a simplified version of the output

from the apparatus correlated with the parts of an upper portion of the bottle;

Figure 7 shows an enlarged version of the output shown in Figure 6;

25   Figure 8 shows an actual output similar to that of Figure 7 but

recorded at a lower amplification so that the output does not reach its maximum

value in the part of the bottle above the foam but below the cap;

Figure 9 shows an actual output similar to that of Figure 8 but

recorded at a still lower amplification so that the output does not reach its maximum

30   value in the region of the bottle containing liquid;

Figure 10 shows a diagrammatic perspective view of the optical assembly shown in Figures 1 and 2 from above and to one side;

Figure 11 shows a diagrammatic three-quarter view of the optical assembly of the apparatus shown in Figure 10 from, above and to one side, with part
5   of the housing of the assembly broken away to show the internal components thereof;

Figure 12 shows a diagrammatic rear elevation of the optical assembly shown in Figures 10 and 11 with part of the housing of the assembly broken away to show the internal components, including the cabling, thereof;

10   Figure 13 is a circuit diagram of the electronics of the optical assembly shown in Figures 10-12;

Figure 14 shows a diagrammatic three-quarter view of the camera of the optical assembly shown in Figures 10-12 from above, in front and to one side;

Figure 15 shows a three-quarter view of the same camera as in Figure
15   14 from above, behind and to one side;

Figure 16 shows an exploded diagrammatic isometric view of the optical system of the camera shown in Figures 14 and 15 from the same angle as in Figure 10;

Figure 17 shows an exploded diagrammatic isometric view, from the
20   same angle as in Figure 16, of the housing, rear cover and electrical connectors of the camera shown in Figures 14-16;

Figure 18 is a circuit diagram of the electronics of the camera shown in Figures 14-17;

Figure 19 shows diagrammatically the optical system of the optical
25   assembly shown in Figures 1 and 10-12 and the relationship between the height of the upper portion of the bottle, the magnification of the optical system and the height of the detector;

Figure 20 shows a wiring diagram of the cables used to interconnect the optical assembly and computer system shown in Figure 1;

Figure 21 shows an exploded isometric view of the light source assembly shown in Figures 1 and 2 from above, in front and to one side;

Figure 22 shows an enlarged three-quarter view of the bridge assembly shown in Figures 1 and 2 from above and to one side;

5   Figure 23 shows an enlarged diagrammatic three-quarter view of the bottle detect assembly shown in Figures 1 and 2 from above and to one side;

Figures 24, 25, and 26 are transmission curves of clear, brown and green glass samples respectively over the wavelength range of 200-900 nm;

Figure 27 is a graph of the variation of the integrated area under a

10   transmission curve such as those shown in Figures 6-9 with time during a procedure (described below) for determining a correction of a HOF measured by the apparatus shown in Figure 1 to allow for the liquid present as foam within a bottle being measured;

Figure 28 is a graph of the variation of the pixel number

15   corresponding to the measured HOF with time during the same procedure as in Figure 27; and

Figure 29 is a graph, derived from the graphs shown in Figures 27 and 28, showing the correction which should be applied to the HOF measured by the apparatus shown in Figure 1 to allow for the liquid present as foam within a bottle

20   being measured.

As already mentioned, in the processes of the present invention a portion of the container is illuminated with electromagnetic radiation. While the illumination conceivably could come from natural lighting or the ambient lighting of the production facility, it is preferably provided in the form of the light source

25   assembly, which could be highly directional in nature, diffuse, or some combination of both, depending on the geometry of illumination and the optical properties of the container under measurement. If the container being measured has lenslike properties and is to be transilluminated, diffuse lighting is preferred since highly directional light passing through a container that has significant optical power

30   presents additional measurement challenges. Apart from the diffuse or directional

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considerations, the lighting may be continuous or strobed (for example, when the
processes are used to measure HOF of a succession of bottles on a filling line, a
strobe lamp could be arranged to flash when a bottle is detected at the measuring
station), and may be positioned above or behind the bottle. Also, front lighting is

5   possible and, if directional, its angle may be from above. While the exact nature of
the lighting may take on various properties, it has been determined but it has already
been found that ambient, back-lit diffuse, and front, angled directional lighting
produce measurable results. The lighting is important for providing sufficient
contrast between the transparent material of the container bottle and its contents, and

10   there must be sufficient light energy to provide an adequate signal to noise ratio.
Preferably, the lighting is such that it does not generate undesired spurious
reflections off the bottle, and polarization techniques could be used to control
spurious reflections. Preferably, the container is transilluminated (that is, the
electromagnetic radiation is caused to pass through the portion of the container of

15   which an image is to be formed) as illustrated in Fig. 6, but alternatively the
container may be illuminated from the objective side (epi-illuminated, so that the
image is formed by reflection or scattering from the contents of the container). In
the former case, the contrast is due to the light transmitted through the empty space
with the container compared with what is transmitted through the contents. In the

20   latter case, the contrast is primarily from what is reflected from the container surface
and what is behind it, either contents or empty space. Lighting sources include
fluorescent bulbs, linear diode arrays, and fiber optic bundles.

Other forms of illumination possible are coaxial, where the radiation
source and detector share a common optical path. When such coaxial illumination is

25   used on a succession of containers passing along a filling line, the illumination
would be directed by the container downstream as the container approached the
detector station, upstream when it was past, and retro-reflected when the container
was "on-axis", i.e., immediately in front of the detector. Alternatively, the
illumination source and detector may be on the same side of the container with their

axes arranged to intersect one another at a slight angle. These two schemes tend to reduce the possibility of unwanted or undesired signals from spurious reflections.

Finally, if spurious reflections cause problems, a "container present" detector can be introduced into the system to instruct the imaging device to take the

5   required measurement only when the container is properly placed in the "measurement station".

The output of the present apparatus can be used for subsequent downstream applications such as "kicking out" defective bottles from the line, providing feedback to adjust upstream nozzle fill rates, providing statistics on

10   process performance, or providing other process related functions, all as described herein.

The whole apparatus is preferably under the control of a central processor or computer system with touch screen control or a graphical user interface running under Microsoft Windows (Registered Trademark) or other suitable

15   operating environment. The apparatus may be networked to interface with other factory control equipment.

A wide variety of containers may be used in the present processes. For example, the processes may be used to measure HOF in containers enclosing pulverulent or granular solid materials, such as fine chemicals, pharmaceuticals or

20   foodstuffs, or materials comprising solids suspended in liquids. The containers themselves can vary widely in size and shape and may have the form of drums, carboys, flasks, jars and bottles. However, the present processes are especially intended for use with containers containing liquids, particularly bottles containing foamable liquids such as beer, and accordingly the detailed description of the

25   processes hereinafter will mainly be with reference to such bottles of foamable liquid, since the necessary modifications of the processes and apparatus for use with other types of containers and contents will readily be apparent to those skilled in the container handling art.

The present processes require that the portion of the container of

30   which the image is to be formed be transparent to the illuminating radiation. The

bottles or other containers will generally be "transparent" in the visible region of the spectrum, but may also be transmissive in other regions, particularly the infra-red. As shown in more detail below with reference to Figs. 24, 25, and 26, color glasses, such as the brown or green glasses often chosen to protect liquids such as beer from

5   the effects of ultra-violet radiation, are transparent in at least the near infra-red, and hence measurement in the infra-red region is within the scope of the invention. Similarly, clear glass and many plastics used to form containers are transparent in the near ultra-violet down to at least 300 nm, and hence measurement in the ultra-violet region is also within the scope of the invention. In addition, other materials

10   may be transparent to X-rays and thus X-ray radiation is contemplated to be within the scope of the invention.

The term "transparent" as used herein does not imply complete or almost complete transmission of the electromagnetic radiation used; it is only necessary that the relevant part of the container transmit sufficient radiation to

15   provide a discernible difference between the amounts of radiation transmitted through the various regions between which it is necessary to distinguish. For example, the Fig. 25 shows that brown glass has a transmission between 30 and 40% over the range of 800-900 nm, and this level of transmission is more than sufficient for the purposes of the present invention.

20   In the optical feature process and apparatus of the present invention, the optically detectable feature may be any feature of the container which can be distinguished by the imaging technique employed, although in practice it is important to choose a feature which has a substantially constant position on the container within the degree of precision required. The optically detectable feature

25   may be, for example, the base of the container, a label, neckband or printing applied to the container, a bulge, lip or other protrusion or recess on the container, or a curved part of the container surface; such curved parts produce refraction effects which can readily be detected as contrasting areas in images of the container. Regardless of what feature is chosen, the optical feature process and apparatus have

30   the important advantage that measuring HOF relative to the feature automatically

compensates for vertical movements of the container such as may occur due to flexibility of a conveyor on which the container is being transported.

As already indicated, the present processes are especially intended for use with bottles or similar containers for foamable liquids such as beer, and such

5   bottles or similar containers will typically have an opening at their upper end and a closure member (for example, a crown cap) substantially closing this opening. With such containers, the optically detectable feature preferably comprises at least part of the closure member. In most cases, the closure member essentially will not transmit the radiation used to illuminate the container, and it is convenient for the data

10   processing means to determine the distance between the upper end of the first region of the image (associated with the top of the closure member) and the upper edge of the second region (associated with the liquid contents below the fill level). Measuring HOF relative to the closure member has the further advantage that the process can be used to detect not only containers having an improper fill level, but

15   also containers having an improperly applied closure member. For example, if a crown cap is applied off-center so that it hangs lower on one side of a bottle than on the other, measuring the fill level relative to the cap in a bottle having the correct fill level will result in an abnormal reading because of the abnormal position of the cap, and the bottle can thus be rejected.

20   In all processes and apparatus of the present invention used with containers comprising a liquid having foam on the surface thereof, it is desirable that the thickness of the foam layer be measured and converted to its equivalent liquid volume. Thus, in the preferred form of the optical feature process and apparatus in which HOF is measured relative to the closure member, the analysis by the data

25   processing means desirably identifies a first region of low radiation transmission associated with the closure member, a second region of high radiation transmission associated with the liquid, and a third region of low radiation transmission associated with the foam. It will be recognized that within each region, the signal will vary in accordance with the optical properties of the region's composition and

30   the significant physical path length. With foam, for example, the variation is

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believed to be a function of the diameter of foam bubbles, the physical path which
the bubbles occupy and the reflection properties of the bubbles at its surfaces, along
with any scattering or absorption present. In many cases, it is preferred that the
analysis determine the vertical height of the region associated with the foam, convert

5   this vertical height to an equivalent vertical height of liquid (a preferred technique
for effecting this conversion is described in detail below), and adjust the determined
HOF to allow for the amount of liquid which would be generated if the foam were
converted to liquid.

Any known form of imaging apparatus can be used to form the image

10   needed in the present processes and apparatus; for example, one could use a video
camera. However, preferably, a solid state detector is used. This may be a linear
charged-coupled device (CCD) array or an area CCD array or some other suitable
detector such as a scanner capable of generating a signal whose intensity over the
desired image area (the measurement zone) varies as a function of the optical

15   properties of that area. Preferably a linear CCD or other similar linear array of
radiation detectors is employed; such linear arrays are inexpensive and analysis of
the images produced from them is simpler and requires much less computing power
than analysis of a two-dimensional image from a video camera. The present
preference is for a silicon based linear CCD array of about 250 pixels although

20   suitable results have been obtained with 128 pixels. Commercial linear CCD's can
be is driven to operate at speeds (frame rates) that are sufficiently fast to provide a
signal corresponding to a small segment of the bottle or other container as it moves
down a conveyor on a filling line. Scan rates can be as high as about 15,000 frames
per second which translates to a signal for at least every eighth of an inch (3 mm) of

25   container travel.

The CCD or other imaging apparatus may be placed immediately
adjacent the container under test. However, in many cases, it may be advantageous
for radiation from the portion of the container being imaged to be passed through an
imaging device so that the image of the portion of the container is formed upon the

30   CCD or other imaging apparatus at a point spaced from the container. Using a

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"remote" CCD in this manner allows for more flexibility in the placement of the various parts of the apparatus (so that, for example, the apparatus may be more easily adjusted for use with various types of filling and other container-handling lines) and also reduces the risk that the CCD and associated electronics will be

5   contaminated if, for example, a liquid-filled bottle on a filling line overflows, explodes or otherwise accidentally distributes its contents over apparatus adjacent the line. The image-forming device desirably is of a type, for example a zoom lens, which allows the magnification of the image formed to be varied, thus enabling a single CCD to be used with a variety of containers of differing sizes. In most cases,

10   it is desirable that the magnification of the image-forming device be less than one, since forming a relatively small image allows a compact, relatively inexpensive CCD to be used.

As already indicated, the present apparatus is primarily intended to be used to measure the HOF of a succession of containers moving along a filling or

15   similar container-handling line, and, in order that the HOF measurement is made at the proper point as each container passes the present apparatus, the apparatus desirably includes conveyor means for moving a plurality of containers in single file past a station, and container detection means for detecting the presence of one of the containers at the station. When the containers are beverage or similar bottles each

20   having an opening at its upper end and a closure member substantially closing the opening, the container detection means conveniently comprises a radiation source arranged to project a first beam of radiation on to the closure member at the station and a radiation detector arranged to detect a second beam produced by reflection of the first beam from the closure member.

25   A preferred apparatus and process of the invention will now be described, though by way of illustration only, with reference to the accompanying drawings.

As best seen in Figs. 1 and 2, the preferred apparatus of the present invention, which is pictured at a measurement station along a bottling line

30   downstream of dispensing units, comprises several major components, the details of

which will become readily apparent in what follows. More particularly, the apparatus provides an optically based, computer controlled, height of fill detection system and associated processes. The apparatus shown in Fig. 1 is generally designated 10, with the bottling line being generally designated 20 and the upstream

5   dispensing units generally designated 30.

The apparatus 10 comprises four (4) main assemblies assembled on a 6 foot (1.83 m) crank stand 90 for accurate and consistent positioning, the first three assemblies being an optical head assembly or optical assembly 40, a light or illumination source assembly 50, and a bridge assembly 60 which connects

10   assemblies 40 and 50, supporting and positioning them to straddle the bottling line 20. On top of the bridge assembly 60 is the fourth assembly, namely a bottle detect assembly 70, which operates to provide a signal indicating the presence of a bottle at a predetermined position between the light source assembly 50 and the optical assembly 40.

15   A computer system 80 (Fig. 1), preferably a workstation or Pentium (Registered Trademark) based personal computer system, provides control and exchange of signals and data between the operator and assemblies 30, 40, 50, 60 and 70. The computer system 80 preferably has a graphical user interface such as a Windows (Registered Trademark) NT or Windows 95 operating system, and the

20   usual input and output devices such as a keyboard and mouse. Information from measurement of bottles is displayed in graphical form on a display monitor, or as numerical data or textual information or combinations of all three. Software and suitable algorithms are preferably provided in the "C" programming language although other languages may be sensibly used as substitutes.

25   The height of assemblies 40, 50, 60 and 70 with respect to the bottles can be adjusted via the crank stand 90. A bottle reject assembly, shown only schematically in Fig. 1 and generally designated 100, is provided adjacent the line 20 downstream from the apparatus 10, to allow for rejection from the line 20 of bottles which the apparatus 10 indicates to be unsatisfactory.

As best seen in the flow chart of Fig. 3, system 10 is first initialized at
102 by an operator who provides proper height positioning and informs the system
about the type of bottles, manufacturer, glass color, height of fill specifications, the
number of cappers and fillers upstream at the dispensing units 30, and the

5   parameters of the bottles that are to be measured and how the measured information
is to be presented and subsequently used. This information is preferably selected via
drop down menus and icons provided as part of the system software. Information
about specific manufacturers' bottles and their specific specifications, shapes,
contents and other important parameters are preferably selected from on-board look-

10   up tables (LUTS) residing in memory or, alternatively, loadable as needed from
peripheral devices.

Following system initialization, a signal is given at 104 to start the
measurement sequence, after which the bottle detect assembly 70 is brought into
operation to provide a signal that a bottle is present in its measurement location. The

15   software loops through a bottle detect operation 106 until the bottle detect assembly
70 indicates the presence of a bottle, whereupon, at 108, a command is issued to the
optical assembly 40 to start scanning a predetermined section of a bottle; scanning
continues over a period of time during which data is acquired and analyzed in real
time or stored and then analyzed a predetermined time later.

20   The data acquired during the scan are then analyzed in a data analysis
section 110 of the software. Depending on what parameters were selected during
initialization, the acquired scan data may be analyzed to determine cap position,
fluid height, foam presence, quality, and/or correction, height of fill, container shape,
color, and feature integrity, or container content color features and transmission

25   characteristics. Thus, while the primary purpose of the invention is height of fill
determination, it is clear that the apparatus and process can also serve as an
inspection device for other types of container properties.

From the data analysis section 110, the software proceeds to a
decision block 112, where the determined HOF is compared with the acceptable

30   limits, and this information is used to determine if a bottle is acceptable or not. If

the HOF is deemed unacceptable, the software proceeds, at 114, to send a reject

signal to the bottle reject assembly 100, which automatically kicks the rejected bottle

off the line 20 by well-known means such as by pneumatic control. If the HOF is

found satisfactory at 112, or after generating the rejection signal at 114, the software

5   proceeds to a further decision block 116, which tests whether the operator has

enabled process control calculations. If so, the software proceeds at 118 to carry out

process control calculations, which are shown in more detail on the right-hand side

of Fig. 3. If process control calculations have not been enabled, or after they have

been completed, the software loops back to the bottle detect block 106.

10   The process control calculation block 118 is shown in more detail on

the right-hand side of Fig. 3, which shows that this block includes a single bottle

data block 120 at which the data for the bottle just measured are added to cumulative

data representing the history of the capper and filler units which processed this

bottle. Next, at 122, the updated cumulative data are saved for later use, and then, at

15   124, the software recalculates statistics for the relevant capper and filler units. The

software then proceeds, at 126, to determine whether the statistics calculated at 124

indicate that any of the capper or filler units have deviated from their proper process

control settings. If so, the software, at 128, effects adjustment of the deviating

capper or filler; this adjustment may be effected automatically, or an appropriate

20   signal may be given on the monitor of the computer system 80 (see Fig. 1) to advise

the operator of the need to carry out the adjustment .At 129, the process continues.

It will thus be seen that the present apparatus may be configured to

operate stand alone or as an integral part of a production line in which it serves to

provide process control feedback and quality statistics.

25   As best seen in Fig. 4, which shows a vertical section through one of

the bottles 138 used on the line 20 (see Fig. 1), each bottle has a circular, upwardly-

convex base 140, upwardly from the periphery of which extends a cylindrical

sidewall 142. At the upper end of this sidewall 142, the bottle narrows in a

frustoconical section 144, which is surmounted by a second cylindrical section 146.

30   This section 146 is in turn surmounted by a second frustoconical section 148 and a

cylindrical neck section 150. The cylindrical neck section 150 has a bead 152 integrally formed on its outer surface and defines an opening 154 at its upper end, this opening being (in a properly processed bottle) completely closed by a closure member in the form of a crown cap 156. The bottle is filled with beer 158 up to a

5   fill level 160 lying within the second frustoconical section 148; note the presence of a meniscus 162 where the beer wets the interior wall of the frustoconical section 148. The maximum diameter of the bottle 138 is 2.5 inch (63 mm) and its maximum height, measured from the lowest point on the base 140 to the top of the crown 156 is 7.65 inch (194 mm), with the fill level 160 being approximately 6.1 inch (155

10   mm) above the lowest point on the base 140. Note that Fig. 4 shows the bottle 138 in its "quiet" state after all foam produced during the filling operation has collapsed. As explained in more detail below, the process of the invention is normally carried out while a substantial amount of foam is still present above the fill level 160, as shown in Fig. 6

15   The apparatus 10 (see Fig. 1) has the capability of measuring the fill level 160 relative to the crown 156 and/or the base 140 of the bottle 138 to a tolerance of symbol 177 \f "Symbol" \s 12± 1 mm. Indeed, if desired, measurement of the fill level 160 could be effected relative to any optically detectable feature of the bottle 138, for example the curved section at the junction of the cylindrical

20   sidewall 142 and the frustoconical section 144, or to an arbitrary reference point external to the bottle or an feature added upstream of the measurement point. The process may also include measurement of the effects of foam, and other container features may be analyzed such as bottle cap integrity, container shape and color, and color or other features of the contents, such as foam quality in the case of those

25   beverages such as beer with foam presence and appearance requirements. The process also has the ability to determine the presence or absence of crowns, poorly applied crowns, crown defects, foam thickness, and foam density. All of the acquired information gathered by way of measurement may be downloaded as previously stated for purposes of providing production statistics and/or feedback

30   control of upstream dispensing stations.

However, as discussed above, it is generally preferred to carry out measurement of the fill level 160 relative to a point on the crown cap 156, conveniently the top thereof, since measuring relative to the cap only requires imaging of a relatively small part of the bottle; for example in the bottle shown in

5   Fig. 4, measurement relative to the cap only requires imaging about a 2 inch (51 mm) portion of the bottle, whereas measurement relative to the base would require imaging more than 6 inches (152 mm) of the bottle. The fill level 160, and thus the HOF, is preferably measured from the center of the neck since that measurement establishes the nominal fluid volume, and the volume due to the presence of the

10   meniscus can be accounted for, depending on the degree of precision required. Foam may also reside above the fluid as shown in Fig. 6, and can be measured and converted to its equivalent fluid volume if specifications demand such precision. A method for doing this will subsequently be described. Note that although, as described below, the apparatus 10 shown in Fig. 1 uses a linear array of radiation

15   detectors arranged to image a vertical strip of the upper part of the bottle 138 (see Fig. 5), since the imaging operation is conducted while the bottles 138 are moving horizontally along the line 20 (as indicated by the arrow 166) at substantial velocity, and since the detectors of the linear array are sampled sequentially during each scan, the effective scan line 168 on which measurements are taken is inclined at a small

20   angle to the vertical. As explained below, the apparatus 10 is designed for use on a filling line with a capacity of 1200 bottles per minute (20 per second). Since each bottle has a diameter of 2.5 inch (63 mm), and since the bottles pass the apparatus 10 with their side walls 142 (Fig. 4) touching each other, the bottles pass the apparatus at 50 inches per second (1.27 m sec^{-1}). Most desirably, the two ends of this scan line

25   168 are separated horizontally by a distance D of not more than about 0.1 inch (2.5 mm) to ensure that the scanning occurs only in the central portion of the neck of the bottle is positioned adjacent the optical assembly 40. To ensure that this horizontal separation does not exceed 0.1 inch (2.5 mm) requires that a single scan be completed within 1/500th of a second, which for a 128 pixel linear array requires a

30   clock speed of at least 64 kHz. Modern linear CCD's can reach this rate without

undue difficulty. In practice, it has been found that a horizontal distance D of 0.1
inch (5 mm) can be tolerated, which requires a scan rate of 32 kHz. As described
below, the linear CCD of the apparatus 10 operates at this scan rate. Provided that
the bottle detect assembly 70 ensures that the scan occurs while a bottle is accurately
5   aligned with the optical assembly 40, the slight inclination of the scan line 168 has
no significant effect on the operation of the apparatus 10.

As already indicated, the apparatus 10 (Fig. 1) is designed to take
linear scan images of radiation transmitted through the bottle under test. The
resulting digital image shows the cap and foam thickness/fill height as reductions of
10   the signal level, and a provides the corresponding output to the computer display.
Fig. 6 shows the bottle 138 of Fig. 4 and a typical (but somewhat simplified)
computer display correlated with the corresponding parts of the bottle; the bottle is
shown with foam above the liquid as is normal when the HOF of the bottle is
measured immediately after filling, as shown in Fig. 1, while Fig. 7 shows an
15   enlarged version of the output signal shown in Fig. 6. Here, the signal is shown
saturated through the bottle and liquid below the fill level 160, in the region
designated AB in Fig. 6. However, the signal need not be saturated with suitable
gain adjustment as explained hereinafter. The signal diminishes at the meniscus 162
immediately above B, and then drops rapidly where foam is present above the fill
20   level, in the region designated BC in Fig. 6. As shown, when foam is present in the
bottle neck, the region BC corresponding to the foam thickness provides a signal that
varies in accordance with the optical properties of the foam, so the presence of foam
in a bottle is a benefit in determining HOF. However, the amount of foam present, if
its presence is appreciable in terms of its equivalent fluid volume, has to be
25   accounted for by suitable conversions (described below) where volumetric
specifications demand precision. If no foam is present, the HOF is still measurable
with the foam thickness approaching zero.

Above the foam, in the region designated CD in Fig. 6, only gas is
present within the neck of the bottle and the signal again becomes saturated. The
30   signal then drops to a very low value in the region designated DE, corresponding to

the radiation being blocked by the opaque cap 156 (see Fig. 4). Finally, above the cap the bottle ceases to obstruct the radiation being detected and the signal again becomes saturated in a region designated EF.

As indicated in Fig. 7, in the preferred process of the invention, the HOF is measured by determining the distance BE, namely the distance between the lower edge of the foam region BC and the upper edge of the cap region DE. It will be seen that, if the layer of foam is so deep that it completely fills the space between the liquid and the cap, the region CD will disappear from the signal and the regions BC and DE will merge to form a single low signal region. However, the distance BE can still be readily determined, since this distance corresponds to the total height of the merged region. Furthermore, it will be apparent to those skilled in software image analysis that software can readily be written which will automatically analyze the signal and determine the distance BE, whether or not the high signal region CD is present or present in different form because occupied by foam.

As already indicated, the signal shown in Figs. 6 and 7 is somewhat simplified for purposes of illustration. In contrast, Fig. 8 shows an actual display of a signal which is generally similar to that shown in Figs. 6 and 7 in that the detector is saturated in the regions AB and EF corresponding to the bulk liquid and the space above the cap respectively (the various regions of the signal are indicated in Figs. 8 and 9 using the same reference letters as in Figs. 6 and 7). The only features of the signal shown in Fig. 8 which are not present in Figs. 6 and 7 are a region AA', which is due to an essentially opaque label present on the bottle, a more gradual change in signal value near C in the upper part of the foam layer (which is due to partial collapse of the foam, with consequent reduction in the number of liquid films present to scatter the radiation), and a sharp peak 170 present in the region DE and due to refraction effects from a bead similar to the bead 152 shown in Fig. 4. It will be seen that, despite these extra features, the desired distance BE can readily and accurately be measured from the signal shown in Fig. 8.

The signal shown in Fig. 9 differs from that shown in Figs. 6, 7 and 8 in that the detector is not saturated in region AB. The signal shown in Fig. 9 also

does not have a region corresponding to the "label" region AA' in Fig. 8, but does have a sharp peak 170' similar to the peak 170 shown in Fig. 8 and produced in the same manner. Finally, the signal shown in Fig. 9 includes an additional peak 172 in the region above the cap, which may be due to reflection of radiation from the cap. As in Figure 8, the desired distance BE can readily and accurately be measured from the signal shown in Fig. 9.

From Figs. 6-9, it will be seen that proper measurement of HOF can be achieved using signals which are saturated over certain regions of the bottle, and using signals which are not saturated, although the former may have certain advantages in eliminating various minor variations in signal level and thus simplifying computerized identification of the various regions. Saturation of the signal can be achieved by control of the light level, electronic amplifier gain, or by setting a software signal threshold.

As already indicated, the signals from the optical assembly, such as those shown in Figs. 6-9, are fed to a signal processor that calculates the fluid level from the signal properties and the adopted reference position. The result may be displayed as a number, as a go/no-go output, or on a graphic display such as the computer monitor of Fig. 1, showing upper and lower reference limits, say R1 and R2, and the actual HOF with respect to those reference points.

Before describing the various components of the apparatus in more detail, it is considered helpful to set forth a list of a set of typical specifications which this apparatus was required to meet in a typical bottling line application:

1. Image measurability and consistency at 1200 bottle per minute speed.

2. Digital output to host unit for data compilation, and bottle acceptance.

3. HOF measurement to symbol 177 \f "Symbol" \s 12± 1mm.

4. Foam thickness integration into HOF calculation.

5. System Packaging build to National Electronic Manufacturers Association (NEMA) 4 standards.

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6. System wiring and interconnect using standard NEMA () 4X rated cabling. This system is wired to interface with the Host computer, with easy interconnect for ease of modification.

7. Image consistency through several bottle color types.

5   8. Object area to provide adjustability to accommodate varying bottle heights.

The Hardware Specification uses a 133Mhz Pentium computer as the host machine, and the C language to develop driving and compilation software. While this is a typical example, it should be clear that the scope of the invention is much broader than the use of the following elements in the combination shown.

10   Where desired to assess color characteristics of bottles or their contents or both, it will be understood that color CCD's may be employed and where shape or other geometric features are contemplated two-dimensional arrays may be sensibly used.

As shown in Figs. 10, 11 and 12, the optical assembly 40 comprises a base plate 402 on which a manually-operable door 404 having a handle 406 is

15   mounted by means of hinges 408. This door 404 protects and provides access to the internal optical and electrical components of the optical assembly 40, and, together with the base plate 402, forms a substantially cuboidal housing for the optical assembly 40. Note that the base plate 402 lies adjacent the crank stand 90, to which it is attached by two (2) 2¼ inch (57 mm)-20NC machine screws. Mounted on the

20   door 404 are a system power switch 410, a laser power switch 412, a laser power indicator light emitting diode (LED) 414 a power connector 416, a signal connector 418 and a detect connector 420, which is connected to the bottle detect assembly 70 in a manner described below; the power and signal connectors 416 and 418 are Turck connectors. The switches and connectors 410-420 are omitted from Figs. 1

25   and 2 for ease of comprehension, but by comparing Figs. 2 and 10, it will be seen that these switches and connectors 410-420 are located on the "back" of the optical assembly 40, i.e., on the surface of the door 404 facing directly away from the light source assembly 50, thus providing maximum protection of these components from any contamination caused by defective bottles on the line 20.

As shown in Figs. 11 and 12, an optical rail 422 is mounted vertically in the center of the base plate 402 and two locating lasers 424 and 426 are mounted vertically one above the other in a side portion of this base plate. Lasers 424 and 426 comprise part of an optical rangefinder that allows the optical head assembly

5   spacing from a bottle to be properly set. To achieve this both lasers are aimed to a point of convergence. As a bottle or a surrogate bottle is moved toward and away from this point, two spots will appear on the surface of the bottle when the separation distance is incorrect. But adjustment of the spacing in the proper direction narrows the separation between the laser beams, and when perfect, they

10   exactly overlap at which point the spacing is correctly set. A mirror assembly 428, including a mirror 430 inclined at 45° to the vertical, is mounted on the rail 422 adjacent the lasers 424 and 426, while a camera assembly 432 is mounted on the lower end of the rail 422 so that its optical axis is pointing vertically upwardly and intersects the center of the mirror 430. As may be seen by comparing Figs. 2 and 11,

15   radiation from the light source assembly 50 passes through the bottles on the line 20 and through a window (not shown) in the side of the door 404 facing the light source assembly, is reflected from the mirror 430 and enters the camera assembly 432.

       Fig. 12 illustrates the wiring harness of the optical assembly 40, this harness being omitted from Fig. 11 to allow full details of the mirror and camera

20   assemblies to be seen. As shown in Fig. 12, a main internal system harness 434 connects the lasers 424 and 426 to the switches and connectors 410-420, while a camera cable 436 connects a 9-pin subminiature D connector 438 on the bottom face of the camera assembly 432 to the system harness 434. The whole apparatus 10 is powered on and off via the power switch 410, while the lasers 424 and 426 are

25   powered by the laser power switch 412 . When the laser power is activated, power to the camera assembly 432 is turned off. The optical assembly 40 is also the location of the system interconnect wiring. All power and signal wiring, internal and external, is connected through this assembly 40. The system harness 434 connects the camera assembly 432 and the locating laser signal and power to the computer

30   system 80 (Fig. 1), as well as routing the detect signal from the bottle detect

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assembly 70. Fig. 13 illustrates the wiring of the system harness 434 and camera cable 436 shown in Fig. 12.

The camera assembly 432 will now be described in detail with reference to Figs. 14-17. The camera assembly itself is composed of two primary

5   subassemblies, namely a camera optics assembly, generally designated 440, which combines the optical components and the CCD printed circuit board (PCB) and is shown in exploded view in Fig. 16, and a rear cover assembly 442, shown in Fig. 17. These two subassemblies 440 and 442 are held together by the engagement of manually-operable latches 444 on the rear cover assembly with detents 446 (best

10   seen in Fig. 16) on the optics assembly 440, thus providing a simple housing designed to allow quick replacement of the CCD PCB.

As best seen in Fig. 16, the optics assembly comprises a mounting base 448 having at one end an integral upstanding flange 450 provided with a central aperture 452 in which the optical components are mounted. These optical

15   components include a 50 mm fixed focal length adjustable focus objective lens 454. (Although various types of lens can be used in the optical assembly, this lens is preferably zooming and may beneficially be of telecentric design. A telecentric optical system is preferable to avoid height of fill variations because a telecentric system, while becoming less sharp, will not change in image height with changes in

20   the distance from the objective to the bottle.) The objective lens 454 is arranged to form an image of at least a predetermined vertical segment of the bottle containing the area of the bottle where the nominal gas/fluid interface is expected to reside for a given bottle configuration and fill level. The image may encompass the cap as well where the cap is to be a reference. The optical components of the optical

25   subassembly 440 also include a 5 mm spacer 456, a C-mount nut 458, and a special mechanical mounting bracket 460 and C-mount barrel spacer 462, which together serve to correctly position and orient the CCD PCB 464 in the camera assembly 432. The PCB 464 carries a single 128 pixel CCD 466 and an amplifier interface connector 468. All the camera assembly electronics were assembled using off-the-

30   shelf parts and breadboarded printed circuit boards. The base plate 448 is itself

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mounted on a Melles Griot optical rail guide 470 (see Figs. 14 and 15), by means of which the whole camera assembly 432 is mounted on the optical rail 422 (see Figs. 11 and 12).

The CCD 466 is a TSL401 CCD made by Texas Instruments and having the following specifications:

A. 128 x 1 Pixel CCD. The pixels are 63.5 micrometers (H) X 55 micrometers with 63.5 micrometers center-to-center

B. 400 pixels-per-inch (16 pixel mm^{-1} sensor pitch

C. 256 Gray-Scale (8-bit) Applications

D. Operation to 2 MHz

E. Single 5-V Supply

F. Spectral sensitivity from 300-1000 nanometers.

G. System Package 8 pin Dip

H. Signal Output: 0-2V.

As shown in Fig. 17, the rear cover assembly 442 comprises a hollow square prismatic camera body 468, which carries the latches 444 and a manually-operable gain adjust knob 469, and a rear cover 472, which carries the connector 438 and a manually-operable offset gain adjust knob 474 (see Fig. 15). The camera body 468 is a stock aluminum extrusion, but the rear cover 474 is modified for use in the present apparatus. The front surface (i.e., the surface facing the lens 454) of the rear cover 472 is provided with four pillars 476, which support an amplifier PCB 478 carrying an inverting amplifier 480, which is an A741 general purpose operational amplifier manufactured by Texas Instruments. An interface connector 482, which mates with the connector 468 (Fig. 16) of the CCD PCB is also connected to the amplifier PCB 478.

Fig. 18 shows the wiring diagram of the camera assembly 432, and the signal/power information required to operate this camera assembly. Some of the information contained has been copied from the original manufacturer's specification. The camera assembly 432 meets the following specifications:

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A. Inverting Amplifier internal to camera to buffer the signal output to match its 0-2V dynamic range to 0 to -10V A/D converter.

B. C-mount style optical mount for Taking lens.

C. Power Requirements

5   C1. +5V to CCD photodiode array

          C2. +15V and -15V for inverting amplifier circuit

          C3. Common Ground

D. Signal Input and Output

          D1. Clock

10   D2 S1

          D3 Analog Out

E. Clock Speed : Approx. 32 kHz (Max. speed 2MHz - potential speed >60X)

15   In the camera assembly 432, the lens 454 is adjusted so that the image of the bottle formed on the CCD 466 (Fig. 16) has a magnification of 0.12-0.13. The reasons for choosing this magnification will now be explained with reference to Fig. 19.

        In determining the object distance from the lens, close consideration of the location of the system window (the window in the door 404, see Fig. 10,

20 through which light enters the optical assembly 40 after passing through a bottle) was made. Because of splash, contamination, and container destruction causing foam and other debris to form on the window, the distance between the unit under test and the window and the distance from the window to the lens was maximized. It will be recalled that the apparatus 10 is designed to measure HOF to ± 1 mm,

25 which in practice means that ± 2 pixels must equal ± 1 mm. The object height H_o in Fig. 19, which corresponds to the vertical height of the section of bottle to be scanned was set to 2.5 inch (63.5 mm) to cover the expected 1.55 inch (39 mm) between the fill level 160 and the upper end of the cap 156 (see Fig. 4), together with a modest distance above the cap, and allowances for expected variations in the

30 height of the fill level 160 and overall vertical movement of the bottles relative to

the apparatus 10. Since the CCD comprises a linear 128 pixel array with a center-to-center spacing of 63.5 μm between adjacent pixels, the total scan line, and thus the maximum image height, H_i, is 0.320 inch (8.13 mm). Thus, the magnification M for optimum image resolution is given by:

$$M = H_i/H_o = 8.13/63.5 = 0.13$$

Also, since the focal length, f, of the lens 454 (see Fig. 14) was determined to be 50.7 mm, the distance X_0 is given by:

$$X_0 = f/M = 50.7/0.13 = 390 \text{ mm (15.35 inch)}$$

and the distance X_i is given by:

$$X_0 = fM = 50.7 \times 0.13 = 6.5 \text{ mm (0.26 inch)}.$$

Finally, the object distance, S_0, and the image distance, S_i, are given by:

$$S_0 = X_0 + f = 440.7 \text{ mm (17.37 inch)}$$

$$S_i = X_i + f = 57.2 \text{ mm (2.25 inch)}$$

The HOF apparatus 10 interfaces with the computer 80 via an interface cable 484 that connects the apparatus to a motor control/analog-digital converter in the computer to drive the system. As shown in Fig. 20, connection between the optical assembly 40 and the computer system 80 is made by this NEMA rated cable 484, that has two Turck connectors 486 and 488 at its optical assembly end, these connectors mating with the power and signal connectors 416 and 418 respectively (see Fig. 13) on the door 404 (see Fig. 10). The computer end of cable 484 is provided with two subminiature D connectors 490 and 492 (having 15 and 25 pins respectively) which are connected to a motor control/analog-digital converter printed circuit board in the computer 80. A second cable 494, which also interconnects the optical assembly 40 and the computer 80 has a Turck connector 496 mated with the detect connector 420 (see Fig. 13) on the door 404 (see Fig. 10) and, at its opposed end, a 4 pin Molex connector 498 mated with a corresponding connector on the computer 80.

If desired, the apparatus 10 may be easily interconnected to a network using the standard 4-pin Turck NEMA rated panel connectors and standard double-ended 4-pin NEMA rated interface cables. Because of system speed constraints,

portage to a network system will make better use of the detection software and hardware.

As shown in Fig. 21, the light source assembly 50 has a cuboidal housing comprising a front panel 502 having an elongate vertical slot 504 cut therein, side panels 506 and 508, a rear panel 510, a bottom panel 512 and a top panel 514, on which is carried a power connector 516. This housing provides a rigid structure to support a fluorescent tube (described below). A lenticular lens 518 is held within the slot 504 in the front panel 502. A vertical electrical mounting panel 520 is held by vertical grooves 522 in the side panels 506 and 508 (only one of the grooves 522 is visible in Fig. 21) parallel to but spaced from the front panel 502 and the rear panel 510. The mounting panel 520 carries two lamp sockets 524 and 526, in which is held a micro fluorescent tube 528. A mirrored reflector 530 is held between the lamp sockets 524 and 526 to reflect light from the tube 528 toward the slot 504 to better utilize the light in the horizontal direction, while a high speed ballast 532 for the tube 528 is mounted on the opposed side of the mounting panel 520 from this tube. The lenticular lens 518 and reflector 530 help to uniformly spread the light over the entire slot 504. Power to the light source assembly 50, supplied via the connector 516, is wired separately from the power to the optical assembly 40.

Light from the tube 528 passing through the lenticular lens 518 backlights the bottles passing along the line 20 (see Fig. 1) and the light passes through the upper portions of these bottles to form the previously described images within the optical assembly 40.

A preferred tube that has been found useful for use in the light source assembly 50 is as follows:

1. Osram Sylvania (2020G)FM6/H/830 Mini-Fluorescent Lamp
2. T2 Lamp diameter
3. 6 watts, 47 volts
4. Initial Lumens: 310
5. Avg. Rated Life: 10,000 Hours

6. Peak Spectral Frequency: 570-630nm

A preferred ballast which has been found useful is as follows:

1. Energy Saver Ballast ES-1-T2-120-F

2. Rated Specifically for T2 Lamps

3. Lamp Wattage: 11 watts

4. Input Voltage: 120 volts

5. Frequency: Approx. 40khz

6. Flicker <3%

The bridge assembly 60 shown in Figure 22 is an assembled
aluminum structure used to locate and mount the bottle detect assembly 70 and the
light source assembly 50. The bridge assembly 60 comprises a flat plate 602 that is
secured to the base plate 402 (see Figs. 2 and 13) of the optical assembly 40 and a
rectangular frame 604 provided with a first set of bores 606 for mounting the bottle
detect assembly 70 and a second set of bores 608 for mounting the light source
assembly 50. The bridge assembly 60 is preferably designed so that its dynamic
properties serve to isolate the assemblies mounted thereon from ambient vibrations
that may be of concern.

As shown in Fig. 23, the bottle detect assembly 70 comprises a
mounting plate 704 having two slots 706 provided along its lateral edges. Although
not shown in Fig. 23, bolts are secured through these slots 706 and into the bores
606 (see Fig. 22) in the bridge assembly 60 to secure the bottle detect assembly 70
fixedly in position on the bridge assembly 60. The front edge of the mounting plate
704 carries a downwardly extending flange 708. An emitter/detector mount 710,
having substantially the form of an inverted "Y", is pivotally mounted on the flange
708 by means of a pin 712 which is journaled into a bore (not visible in Fig. 23) in
the flange 708. A second pin 714 on the mount 710 is engaged in an arcuate slot
716 cut in the flange 708, and serves to limit the pivoting of the mount 710 relative
to the flange 708.

The lower limbs 718 and 720 of the mount 710 each extend
downwardly at an angle of about 45° to the vertical and are each provided with an

elongate slot 721 and 722, respectively, extending completely through the limb. An emitter 724, which may have the form of a light emitting diode, is mounted in the slot 721 so that the beam from the emitter extends downwardly at an angle of about 45° to the vertical. A detector 726 is similarly mounted within the slot 722. Cables 728 and 730 extend from the emitter 724 and the detector 726 respectively to a mounting block 732 fixedly mounted on the mount 704, and are there connected to a connector 702, which is used to distribute power and transfer signals via a complementary connector not shown but linked with the central computer. When a bottle passes beneath the assembly 70, the beam from the emitter 724 strikes the cap 156 (see Fig. 4) of the bottle, and the reflected beam from the cap is detected by the detector 726, which sends a signal via the cable 730 and the connector 702 to cause the optical assembly 40 to begin the scanning process. If desired, a second bottle detector, for example a mechanical switch, may be provided in the apparatus 10; detection of a bottle by such a mechanical switch, coupled with failure of the bottle detect assembly to detect the same bottle, indicates a bottle lacking a cap, which should be rejected by the bottle reject assembly 100 (see Fig. 1). This is apparent because the mechanical system will indicate that a bottle is present while the lack of a cap will cause no return signal from the absent but anticipated cap.

Figures 24, 25 and 26 show transmission curves for typical clear, brown and green glasses respectively. From these transmission curves, it will be seen that the brown glass is essentially opaque to wavelengths below about 500 nm, while the transmission of the green glass varies in a rather irregular manner below about 700 nm. However, all three glasses have fairly flat curves above 700 nm, in the near infra-red region. Accordingly, to permit the present apparatus to be used with all three types of glass, it is advantageous to use a radiation source which has substantial emission in this region. The preferred fluorescent tube described above emits a spectrum which has similar transmission through brown, green and clear glass beverage containers.

There will now be described a simple algorithm, applicable when back lighting is used, for determining cap height and fluid height in the "Height of

Fill" (HOF) system. The following methodology also allows for correction of the measured HOF for foam in bottles that contain a foamy fluid. Foam correction can be used on any bottled fluid that has foam in the space between the top of the fluid and the cap or lid of the bottle.

5   A bottle is considered to be back lit when the bottle is located between the source (such as the assembly 50) and the detector (such as the linear CCD array 466, see Fig. 16). The light emitted from the source either passes through features of the bottle or is blocked by the bottle. The light that passes through the bottle is focused on the detector.

10   To calibrate the apparatus for foam measurement, place a bottle (unshaken so as to contain no foam) in the apparatus. Adjust the overall gain of the detector until the detector is saturated everywhere except in the regions blocked by the cap and by the meniscus of the fluid, i.e., so that the curve of output versus pixel number is similar to that shown in Figs. 6 and 7 except that, since no foam is

15   present, the region BC is of much smaller width, being confined solely to the meniscus of the fluid. Store the saturated level in memory for later use. Note that such saturation is not absolutely required.

Once the system has been calibrated in this way, the following very simple algorithm can be used to determine the position of the top of the cap and the

20   fluid height. First the cap and fluid pixels (i.e., the pixels on the detector corresponding to the top of the cap and the top of the fluid) are found by transferring the CCD array data to memory. Starting with pixel-1, search in an upward direction (pixel-1, pixel-2, etc...) for the first pixel that is at 95% to 99% percent of the saturated level. That is the cap pixel corresponding to the top of the cap. Then,

25   starting with the last pixel search in a downward direction (pixel-N, pixel-(N-1), etc...) for the last pixel that is at 95% to 99% of the saturated level. That is the fluid pixel corresponding to the top of the fluid.

The above algorithm works very well for finding the data (cap and fluid pixel location) necessary to determine the height of fill in a bottle. This

30   algorithm does not, however, take into account the additional volume of fluid in the

bottle that is in the form of foam. Better measurements of the height of fill take into account this additional volume of fluid, and therefore correct the fill level, to allow for liquid present in the foam.

The foam calibration/correction may be determined as follows. Light passing through the neck of a bottle will be scattered and blocked by foam. The transmission at any given position in the neck will be altered due to the presence and density of the foam at that position. The total decrease in transmission integrated over the entire bottle neck can be used to determine the volume of fluid contained in the foam. Determining a foam correction curve for each bottle/fluid combination eliminates the need to factor out the volume effect due to bottle geometry.

To determine the necessary foam correction, vigorously shake a bottle. Place it in the HOF apparatus, and every (say) 30 seconds scan the bottle, find the cap pixel, fluid pixel, and integrated area under the detector data curve. Perform scans until the foam has completely decayed away, typically at the end of roughly one hour. Thereafter, plot cap pixel, fluid pixel and integrated area as a function of time from the point of maximum foam to no-foam. Fig. 27 shows a typical graph of integrated area against time, while Fig. 28 shows a typical graph of fluid pixel number against time. Notice that the cap pixel should not vary with time, the integrated area decreases as the foam decays, and the fluid height will increase as the foam decays (and accordingly, the fluid pixel number, which is measured downwardly from the top of the scanned region will decrease).

A functional relationship for pixel correction factor versus decreased transmission due to the presence of foam can now be determined. Subtract the base line (no-foam) fluid-height pixel value (determined from the right-hand side of Fig. 28) from the fluid-height pixel values obtained in the timed data series, then plot this change in fluid-height pixel value versus the area under the transmission curve. The resultant graph is shown in Fig. 29. The area under the transmission curve can be further corrected for the area that appears under the curve that is due solely to the cap, glinting of the neck, and the meniscus. This area correction is not necessary for the foam correction to work.

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A function or look-up table can then be generated for this data. This table or function will then be the foam calibration record for the given bottle with the given fluid.

Example: The integrated area of a scanned bottle was found to be 14373 units. From Fig. 29, we see that we will need to subtract 2 pixels from the value of the fluid pixel value. Pixels are subtracted since we are counting pixels from the top down; a higher fluid level corresponds to a lower pixel value.

The magnification of the optics of the system can then be used to transform the cap pixel and corrected fluid pixel into real values of the height of fill. The step nature of the fluid pixel level is due to limits in magnification and resolution of the system. Thus, an improved foam calibration curve can be generated using a CCD array with 256 pixels instead of the 128 pixels described above.

This simple "area under the curve" method of foam calibration ignores any analytical consideration of foam quality, but is believed to inherently take it into account. A foam correction performed in this manner ignores the fact that a bottle with very dense foam in half of the neck and a bottle with slightly less dense foam in all of the neck may have the same integrated area under the transmission curve.

It will be apparent to those skilled in the art that numerous variations on the above techniques for determining HOF and correcting the determined value for liquid present as foam may be employed in the present invention. For example, if the transmission/pixel number curve resembles that in Fig. 9 with only the area above the cap saturated, the location E can be found by scanning upwardly from the first pixel, first locating the region FE, which contains several pixels exhibiting saturation, and then determining the first pixel which shows less than (say) 90% of the saturation value. To find the location B, corresponding to the top of the liquid and the beginning of the foam, one could scan downwardly from the highest-numbered pixel and determine the first pixel showing an output less than a threshold T, which may be arbitrarily set at (say) 50% of the saturation level. However, in

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view of the complexity of the curve shown in Fig. 9, and the possibility that, for example, the bottom of the depression denoted "U" in that Figure might, in some bottles, extend below the threshold T, it is desirable that the software check that several pixels, having numbers immediately below the probable location B

5   determined in this manner, all have values lower than T, i.e., the software should check that there is a substantial dark region BC, corresponding to a significant thickness of foam, present immediately above (to the left in Fig. 9) of the probable location B. This of course assumes that one can rely on such a thickness of foam being present; in practice, when the present processes are used on a filling line using

10   a foamable liquid, this assumption is normally entirely safe.

Note that, even if the location B determined in this manner is displaced by a few pixels from the "true" location B (because the curve does not pass the threshold T for a few pixels after its begins its downward slope corresponding to the transition from liquid to foam), this displacement is of little

15   practical consequence, provided that the apparatus is calibrated using a bottle comparable to those which will be measured, since the same displacement can be expected in all cases. In effect, one is comparing the bottles being tested with the properly-filled bottle used for calibration, rather than seeking to measure an "absolute" HOF.

20   Similar modifications may be made to the procedure described above for correcting for liquid present in the foam. For example, in an "unsaturated" curve such as that shown in Fig. 9, it is quite likely that the irregular curve in the region AB will vary somewhat from bottle to bottle, which would introduce errors in the determination of the area under the curve. To reduce such errors, it may be desirable

25   to determine the area under the curve only within the region BE. Alternatively, one might determine the foam thickness directly by continuing the downward pixel scan past location B and finding location C directly, for example by measuring the point at which the curve (read from right to left in the downward scan being discussed) rises above the threshold T and remains above this threshold for several pixels.

30   However, if location C is to be determined in this manner, the software should allow

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for the possibility that the foam layer completely fills the neck of the bottle, so that the signal remains below the threshold T over the entire region BE.

  It will be apparent to those skilled in computer programming that all of the techniques described above for determining HOF and correcting for liquid present as foam can be implemented by routine programming techniques which are well within the present level of skill in the programming art.

  Other embodiments and variations in the invention will be obvious to those skilled in the art having the benefit of the foregoing disclosure.

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CLAIMS

1   1.   A process for determining the height-of-fill of a container

2   comprising a body having an optically detectable feature, and contents filling the body

3   up to a fill level, at least a measuring portion of the container extending from the

4   optically detectable feature to the fill level being capable of transmitting

5   electromagnetic radiation, which process comprises:

6   illuminating at least the measuring portion of the container with

7   electromagnetic radiation;

8   the process being characterized by forming an image of part of the

9   measuring portion of the container; and

10   analyzing the image by data processing means to identify:

11   (a)   a first region having a first intensity that varies in

12   accordance with the properties of the optically detectable feature; and

13   (b)   a second region having a second intensity that varies in

14   accordance with the optical properties of the contents below the fill

15   level,

16   and determining the distance between a point within the first region

17   and the upper edge of the second region, thereby determining the height-of-fill.

1   2.   A process according to claim 1 characterized in that the

2   container has an opening at its upper end and a closure member substantially closing

3   the opening, and in that the optically detectable feature comprises at least part of the

4   closure member.

1   3.   A process according to claim 2 characterized in that the closure

2   member essentially does not transmit the radiation, and the analysis determines the

3   distance between the upper end of the first region and the upper edge of the second

4   region.

1   4.   A process according to claim 2 or 3 characterized in that the

2   contents comprise a liquid having foam on the surface thereof, and the analysis

3   identifies the first region of low radiation transmission associated with the closure

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4   member, the second region of high radiation transmission associated with the liquid,

5   and a third region of low radiation transmission associated with the foam.

1   5.   A process for determining the height-of-fill of a container

2   comprising a body, foamable liquid contents filling the body up to a fill level, and

3   foam resting upon the liquid contents and extending from the fill level up to a foam

4   level, at least an upper portion of the container extending from below the fill level to

5   the foam level being capable of transmitting electromagnetic radiation, which process

6   comprises:

7   illuminating at least the upper portion of the container with electro-

8   magnetic radiation,

9   the process being characterized by forming an image of part of the

10 upper portion of the container; and

11 analyzing the image by data processing means to identify:

12 (a)   a first region having a first intensity that varies in

13 accordance with the optical properties of the foam; and

14 (b)   a second region having a second intensity that varies in

15 accordance with the optical properties of the liquid contents,

16 and determining the position of the boundary between the first and

17 second regions, thereby determining the height-of-fill.

1   6.   A process according to claim 4 or 5 characterized by

2   determining the vertical height of the foam, converting this vertical height to an

3   equivalent vertical height of liquid, and adjusting the determined height-of–fill for the

4   amount of liquid which would be generated if the foam were converted to liquid.

1   7.   A process according to any one of the preceding claims

2   characterized in that the radiation is infra-red radiation.

1   8.   A process according to any one of the preceding claims

2   characterized in that the image is formed by a linear array of radiation detectors.

1   9.   A process according to any one of the preceding claims

2   characterized by moving a plurality of the containers in single file past a station at

3   which the containers are illuminated with the electromagnetic radiation and the

4   images of the containers are formed, and detecting the presence of one of the

5   containers at the station prior to forming the image thereof.

1   10.   A process according to claim 9 characterized in that the

2   presence of one of the containers at the station is effected by projected a first beam of

3   radiation on to the container at the station and detecting the second beam produced by

4   reflection of the first beam from the container.

1   11.   Apparatus for determining the height-of-fill of a container

2   comprising a body having an optically detectable feature. and contents filling the body

3   up to a fill level, at least a measuring portion of the container extending from the

4   optically detectable feature to the fill level being capable of transmitting

5   electromagnetic radiation, the apparatus being characterized by:

6   image-forming means arranged to form an image of part of the

7   measuring portion of the container; and

8   data processing means for analyzing the image, the data processing

9   means being programmed to identify in the image:

10   (a)   a first region having a first intensity that varies in

11   accordance with the properties of the optically detectable feature; and

12   (b)   a second region having a second intensity that varies in

13   accordance with the optical properties of the contents below the fill

14   level,

15   and to determine the distance between a point within the first region

16   and the upper edge of the second region, thereby determining the height-of-fill of the

17   container.

1   12.   Apparatus according to claim 11 characterized by a radiation

2   source arranged to pass radiation through the measuring portion of the container.

1   13.   Apparatus according to claim 11 or 12 for use with containers

2   each having an opening at its upper end and a closure member substantially closing

3   the opening, characterized in that the data processing means is programmed to detect

4   as the first region at least part of the closure member and to determine the distance

5 between the upper end of the closure member and the upper edge of the second

6 region.

1   14.   Apparatus for determining the height-of-fill of a container

2 comprising a body, foamable liquid contents filling the body up to a fill level, and

3 foam resting upon the liquid contents and extending from the fill level up to a foam

4 level, at least an upper portion of the container extending from below the fill level to

5 the foam level being capable of transmitting electromagnetic radiation, the apparatus

6 being characterized by:

7   image-forming means arranged to form an image of the upper portion

8 of the container; and

9   data processing means for analyzing the image, the data processing

10 means being programmed to identify in the image:

11   (a)   a first region having a first intensity that varies in

12   accordance with the optical properties of the foam; and

13   (b)   a second region having a second intensity that varies in

14   accordance with the optical properties of the liquid contents,

15   and to determine the position of the boundary between the first and

16 second regions, thereby determining the height-of-fill.

1   15.   Apparatus according to any one of claims 12 to 14

2 characterized in that the data processing means is programmed to determine the

3 vertical height of the foam, to convert this vertical height to an equivalent vertical

4 height of liquid, and to adjust the determined height-of–fill for the amount of liquid

5 which would be generated if the foam were converted to liquid.

1   16.   Apparatus according to any one of claims 12 to 15

2 characterized by a radiation source arranged to pass infra-red radiation through the

3 upper portion of the container

1   17.   Apparatus according to any one of claims 12 to 16

2 characterized in that the image-forming means comprises a linear array of radiation

3 detectors.

1   18.   Apparatus according to any one of claims 12 to 17

2   characterized by conveyor means for moving a plurality of the containers in single file

3   past a station, and container detection means for detecting the presence of one of the

4   containers at the station.

1   19.   Apparatus according to claim 18 characterized in that the

2   container detection means comprises a radiation source arranged to project a first

3   beam of radiation on to the container at the station and a radiation detector arranged to

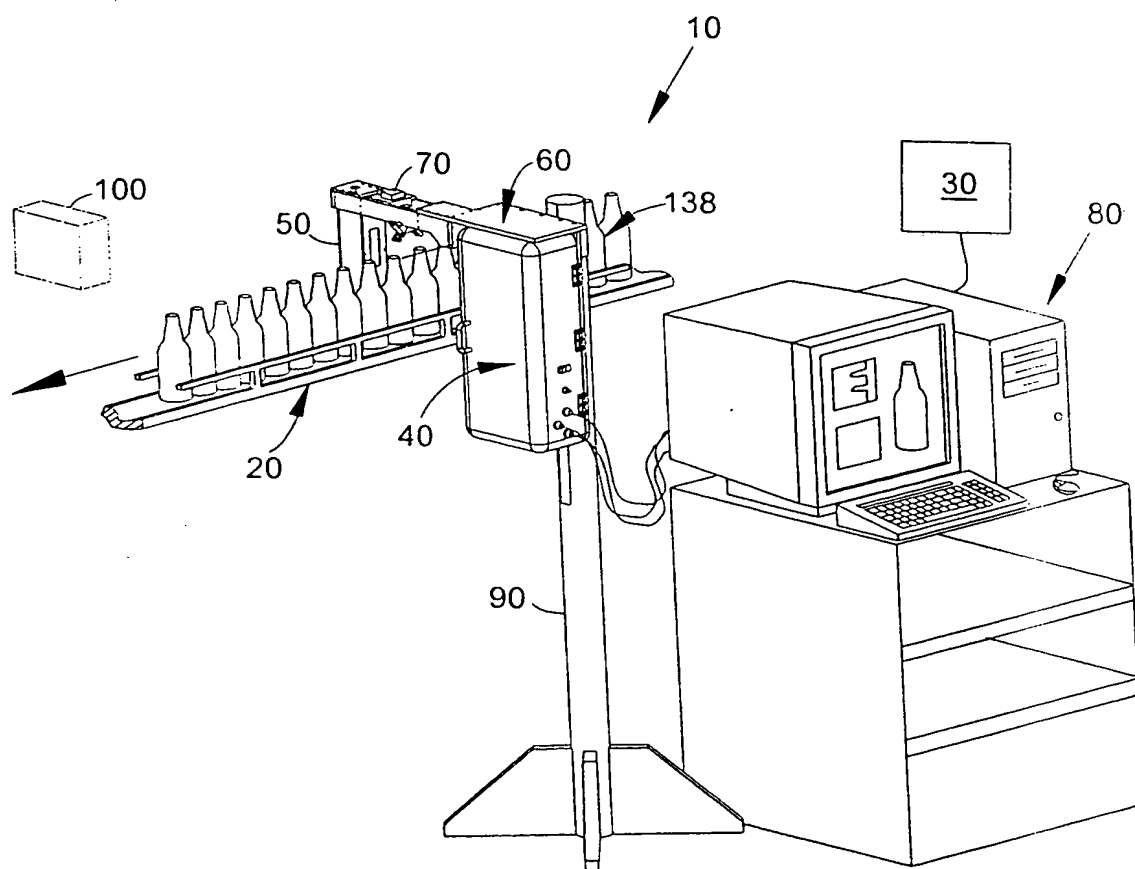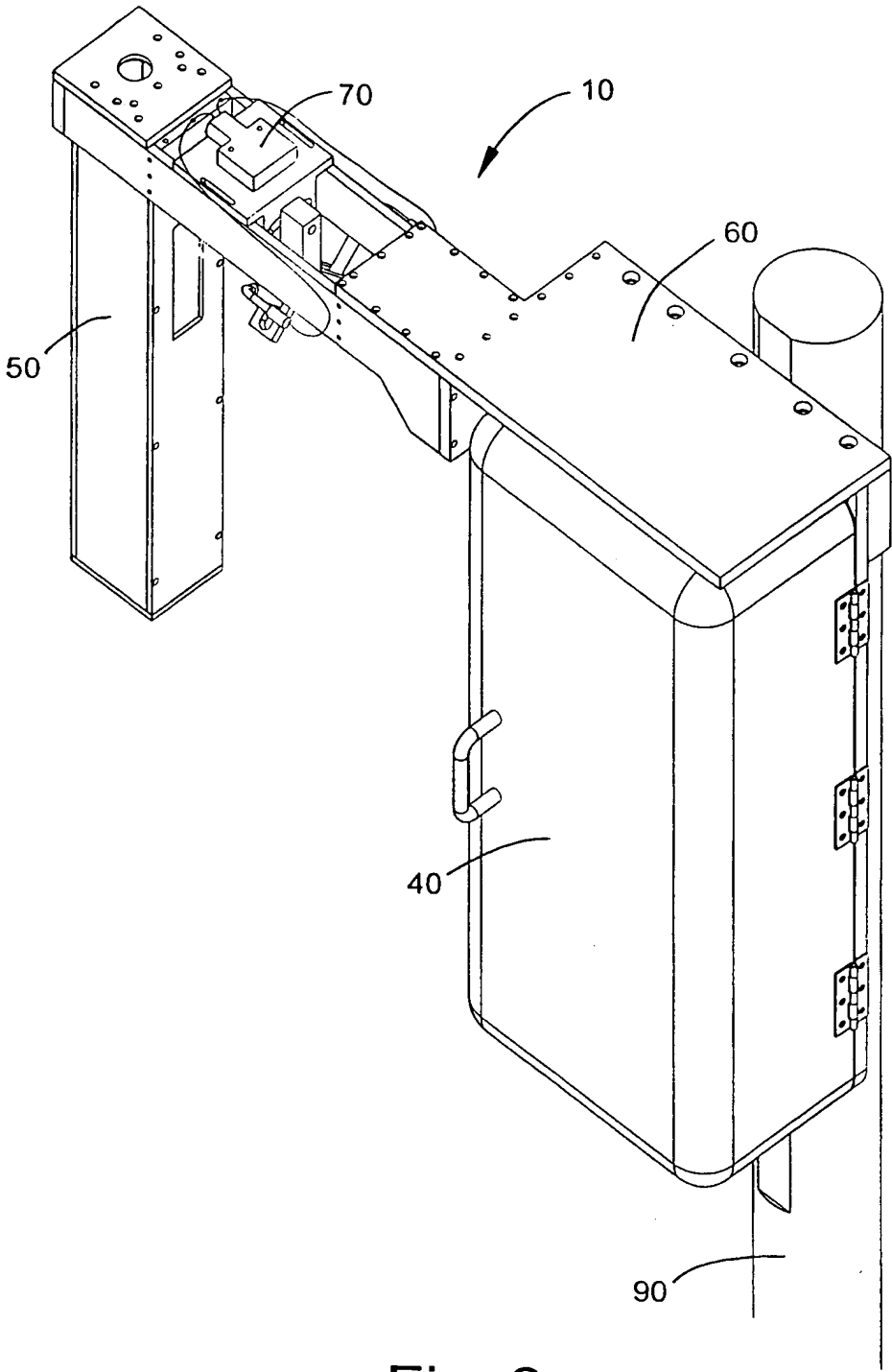4   detect a second beam produced by reflection of the first beam from the container.
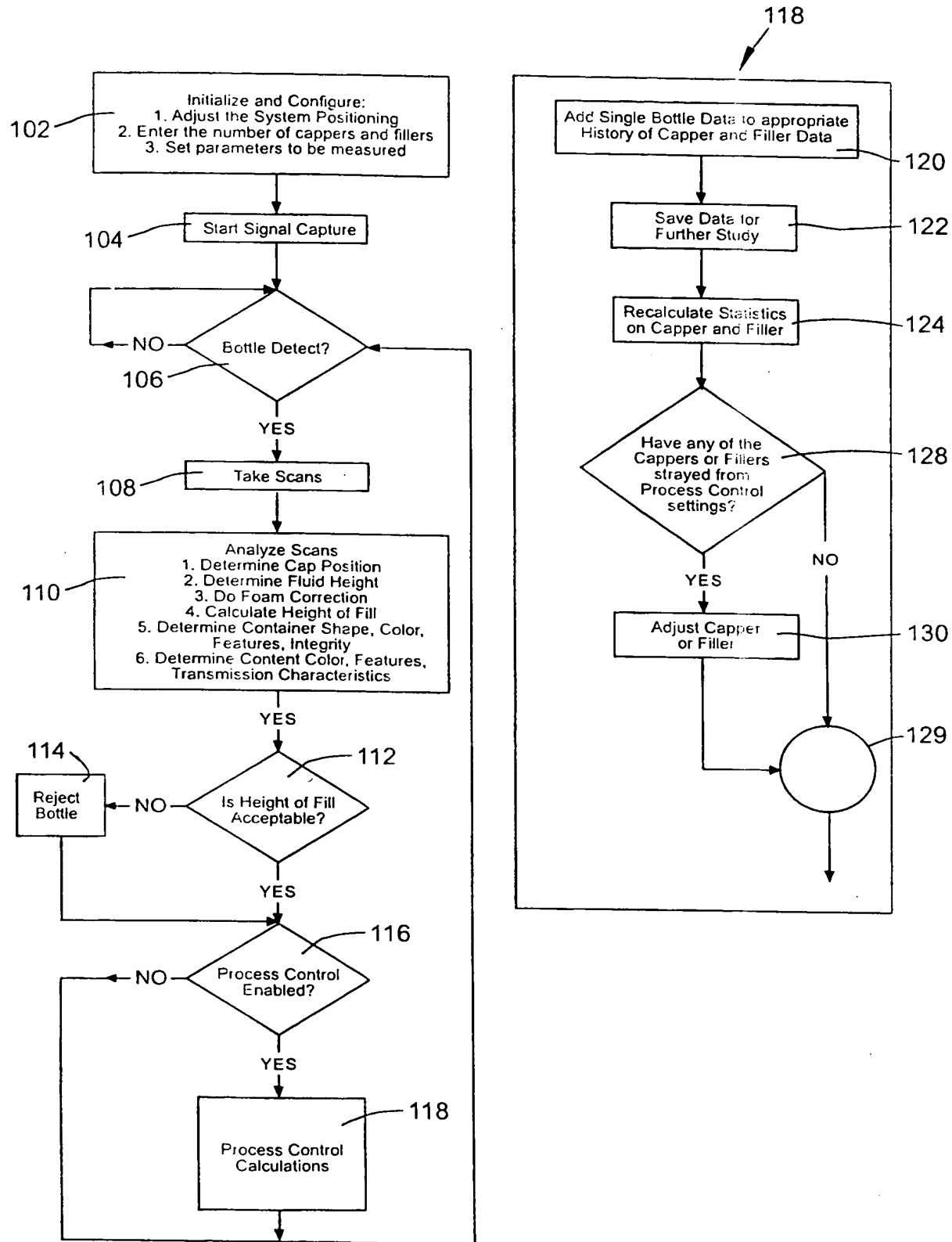
FIG. 1

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Fig. 2

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                                                           ┌─ 118
    ┌────────────────────────────────────┐        ┌──────────────────────────────────────┐
102 │ Initialize and Configure:          │        │  ┌────────────────────────────┐      │
────│ 1. Adjust the System Positioning   │        │  │ Add Single Bottle Data to  │      │
    │ 2. Enter the number of cappers and │        │  │ appropriate History of     │── 120│
    │    fillers                         │        │  │ Capper and Filler Data     │      │
    │ 3. Set parameters to be measured   │        │  └────────────────────────────┘      │
    └────────────────────────────────────┘        │              │                       │
                    │                              │              ▼                       │
                    ▼                              │  ┌────────────────────────────┐      │
104 ┌───────────────────────┐                     │  │  Save Data for             │── 122│
────│  Start Signal Capture  │                     │  │  Further Study             │      │
    └───────────────────────┘                     │  └────────────────────────────┘      │
                    │                              │              │                       │
                    ▼                              │              ▼                       │
         ◇────────────────◇                       │  ┌────────────────────────────┐      │
    NO──◇  Bottle Detect?  ◇──                     │  │  Recalculate Statistics    │── 124│
         ◇────────────────◇ │                      │  │  on Capper and Filler      │      │
      106       │                                  │  └────────────────────────────┘      │
              YES                                  │              │                       │
                │                                  │              ▼                       │
                ▼                                  │      ◇───────────────◇               │
108 ┌───────────────────┐                          │     ◇ Have any of the ◇── 128        │
────│    Take Scans     │                          │     ◇ Cappers or Fillers◇            │
    └───────────────────┘                          │     ◇ strayed from     ◇            │
                │                                  │     ◇ Process Control  ◇            │
                ▼                                  │     ◇ settings?        ◇            │
    ┌────────────────────────────────────┐         │      ◇───────────────◇     NO        │
    │ Analyze Scans                      │         │           │            │            │
110 │ 1. Determine Cap Position          │         │         YES            │            │
────│ 2. Determine Fluid Height          │         │           ▼            │            │
    │ 3. Do Foam Correction              │         │  ┌─────────────────┐   │            │
    │ 4. Calculate Height of Fill        │         │  │ Adjust Capper   │── 130           │
    │ 5. Determine Container Shape, Color,│        │  │ or Filler       │   │            │
    │    Features, Integrity             │         │  └─────────────────┘   │            │
    │ 6. Determine Content Color, Features,│       │           │            ▼            │
    │    Transmission Characteristics    │         │           │         ⊙── 129         │
    └────────────────────────────────────┘         │           └────────►⊙              │
                │                                  │                      │             │
              YES                                  │                      ▼             │
                ▼                                  └──────────────────────────────────────┘
         ◇───────────────◇── 112
114  NO─◇ Is Height of Fill◇
┌──────┐  ◇  Acceptable?   ◇
│Reject│  ◇───────────────◇
│Bottle│       │
└──────┘     YES
    │          ▼
    └─────►◇───────────────◇── 116
         NO─◇ Process Control◇
            ◇  Enabled?     ◇
            ◇───────────────◇
                 │
               YES
                 ▼
    ┌───────────────────────┐── 118
    │  Process Control       │
    │  Calculations          │
    └───────────────────────┘
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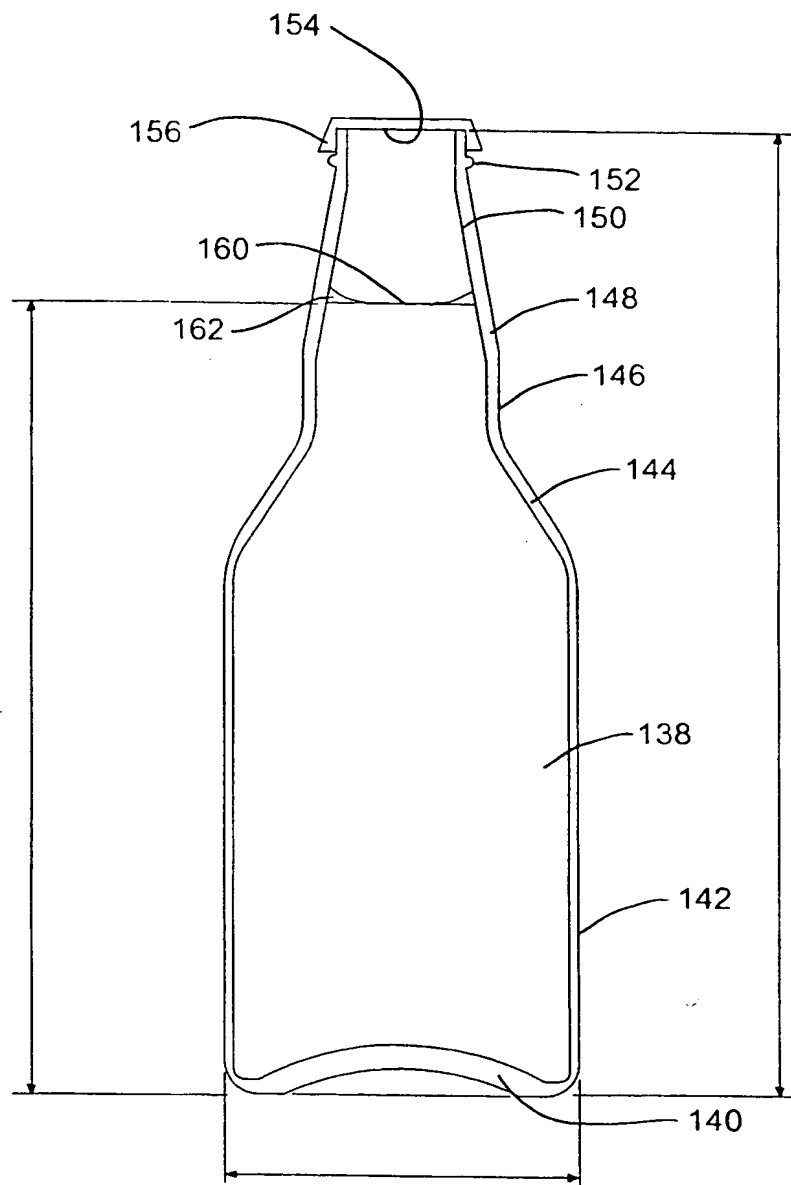
FIG. 3

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FIG. 4

FIG. 5

FIG. 6

FIG. 7

FIG. 8

FIG. 9

FIG. 10

FIG. 11

FIG. 12

FIG. 13

FIG. 14

FIG. 15

FIG. 16

FIG. 17

FIG. 18

FIG. 19

FIG. 20

FIG. 21

FIG. 22

FIG. 23

FIG. 24

BROWN GLASS

FIG. 25

GREEN GLASS

FIG. 26

Integrated Area vs Time (min)

FIG. 27

Fluid Pixel Number vs Time (min)

FIG. 28

Pixel Correction vs Foam Area

FIG. 29

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   G01F23/292

According to International Patent Classification(IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   G01F   B67C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR 2 582 804 A (PRIMAT DIDIER) 5 December 1986	1-3,8, 11-13,17
Y	see page 5, line 9 - line 32; figures 1-6	4-6,9, 10,14, 16,18,19
	see page 6, line 14 - page 7, line 1 see page 9, line 23 - line 32 ---	
Y	EP 0 753 730 A (SOUCHON NEUVESEL VERRERIES) 15 January 1997 see abstract; claim 1; figures 3-8 ---	4,5,14
Y	US 5 568 262 A (LACHAPELLE JOSEPH G ET AL) 22 October 1996 see column 7, line 5 - line 42; figures 3,8 ---	6,16
	-/--	

[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 July 1998	20/07/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Boerrigter, H

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page 1 of 2

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 369 713 A (SCHWARTZ NIRA ET AL) 29 November 1994 see column 3, line 59 - column 4, line 37; figure 1 ---	9,10,18, 19
X	WO 92 14142 A (NOVONORDISK AS) 20 August 1992 see page 16, line 23 - page 17, line 17; figures 4,5 ---	1-3, 11-13
A	US 3 232 429 A (NORWICH ALAN) 1 February 1966 cited in the application see column 1, line 35 - line 47; figure 2 -----	6,15

2

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

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			AU 1233492 A		07-09-1992
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